Using magnetic resonance images for locating anatomical targets

The invention relates to a method and a system for using magnetic resonance (MR) images in radiotherapy treatment planning (RTP).

Radiotherapy treatment planning is the calculation of the delivery of a precise dose of radiation to a specific volume of tissue within the patient. Medical equipment for
5   radiation therapy treats tumorous tissue with high energy radiation. The amount of radiation and its placement must be accurately controlled to ensure that the tumor receives sufficient radiation to be destroyed and that damage to the surrounding and adjacent non-tumorous tissue is minimized. The high energy radiation is collimated to direct a beam into the patient to the lesion. In the case of treatment planning for external beam therapy the output of a
10 treatment plan would normally be a schema for a determined number of external treatment beams of radiation including their cross sectional dimensions and the length of time for which they are turned on, angular orientations about the patient, angular rotation about the central beam axis, and instructions for the precise set up of these beams on the patient surface to allow the beams to intersect in the treatment volume. Specific orientations of the patient
15 treatment couch may also be included.

Internal source radiation therapy (referred to as brachytherapy) places capsules of radioactive material inside the patient in proximity to the tumorous tissue. Dose and placement are accurately controlled by the physical positioning of the isotope. In this case, the treatment planning for intra cavity treatment, the treatment plan would include the
20 number of radioactive sources to be inserted, their activity and the overall time for which they are inserted, their precise position within the patient and the positions of any non-radioactive spacers.

Recent advances have allowed MR images to be used as the radiotherapy treatment planning modality. Magnetic resonance imaging (MRI) is superior to computerized
25 tomography (CT) for providing non-invasive visualization of internal anatomic structures because its scans provide higher quality definition of the anatomy and better differentiation between normal and abnormal tissue. Further, MR images can be obtained in all three standard views; i.e. front view, side view and cross-section (designated as coronal, sagittal and axial views respectively). These three views significantly improve the ability of the

2

physician to develop a 3-dimensional comprehension of the interrelation of structures which improves diagnostic interpretation as well as therapeutic intervention. The interaction between the radiation treatment beams and the patient tissue is planned out using patient MR image data. It is most important that this image data is linear, i.e. geometrically undistorted.

5   The use of MR in RT planning has required the development of gradient distortion correction software to impose linearity on the 3D image data set used for planning. However, the distance away from the isocenter of the field of view (FOV) at which this linearity starts to break down leads to inaccuracies in planning treatments for larger patients. In particular, radiotherapy treatment set-up requires the use of patient surface markers and these are, by

10   definition, further away from the isocenter of the magnet when the patient is placed centrally for imaging. These are therefore susceptible to any remaining inherent image distortion.

Legal requirements for the delivery of the correct physician prescribed dose to the treatment volume result in very small tolerances in physical errors. Typically, when planning using CT slices, the planner would aim to calculate all measurements in the schema

15   to the nearest millimeter or nearest degree. The inherent distortion in MR images therefore means that in some cases they are not suitable enough for radiotherapy treatment planning, even though MR produces superior soft tissue resolution.

20   U.S. Pat. No. 5,800,353 to Robert L. McLaurin, Jr. discloses a medical procedure which accepts that MR scans contain an inherent distortion, but solves the problem of how to use them for treatment planning by aligning all scans relative to a machine frame of reference. For imaging a framework over the body containing fiducial markers is used and the distortion in the resulting images is considered by analyzing the final positions of the

25   fiducial markers in the resulting images.

U.S. Pat. No. 6,466,813 to Himanshu P. Shukla et. al. discloses the use of MR images in radiation treatment planning and includes a correction for distortion. However, it is not clearly disclosed in which way this correction for distortion is performed, and after correction the linearity at larger distance from isocenter breaks down beyond acceptable

30   accuracy.

There is a need, therefore, for a method and system which improves accuracy in MR-based Radiation Therapy planning and simulation.

The present invention contemplates a new and improved method and a system to overcome the above mentioned problems and discloses a method by which MR images

3

may be used in radiotherapy treatment planning using magnetic resonance image data as primary data set by repositioning of patient for higher accuracy of fiducial markers position.

  To accomplish the above, using the MR acquired images exclusively, the patient is imaged with the anatomical target in the magnetic center (isocenter) of the MR

5 system to visualize and locate the lesion or tumor. One or more fiducial markers placed on the patient away from the isocenter are imaged successively, in such a way that the marker is closer to isocenter and therefore its position is known more accurately. The accurate position of the marker is then merged into the first image. If needed, this procedure can be repeated for further fiducial markers. The accurate position of the fiducial marker can be determined

10 by the measured shift of the patient table. On the other hand a composite image data set can be built up by merging the first and second images by overlapping corresponding parts in the images.

15   It is a further object of the present invention to provide a system using an open MR imager as imaging device, which permits the patient to be inserted sideways and to reposition the patient table in almost any direction.

20   These and other objects and advantages of the invention will become apparent to those skilled in the art upon a study of the following description and the accompanying drawings, in which:

  Fig. 1 shows three imaging positions of a patient for accurate geometric position

25 a)   of lesion,

b)   of a right marker and

c)   of a left marker;

  Fig. 2 shows three imaging positions of a patient for accurate geometric position

30 a)   of lesion,

b)   of a right anterior and posterior marker and

c)   of a left anterior and posterior marker.

  Fig. 3 shows three imaging positions of a patient for accurate geometric position

4

a)   of lesion,

b)   of an anterior marker and

c)   of a posterior marker.

5

Image-based radiation therapy planning (RTP) requires images with as little spatial distortion as possible. During successive radiation therapy treatment sessions, the patient is positioned in the radiation therapy device using external markers, or fiducial markers, which are either semi-permanently attached or marked on the patient, or on a

10   fixation mask or device which forces the patient into the same identical position. The spatial relation between the external, or fiducial, markers and the internal location of the lesion needs to be correct, since this is used to plan the radiation therapy. Any inaccuracies result in sub-optimal treatment, since the radiation will be focused not exactly at the actual position of the lesion.

15   In CT-based RTP, the spatial accuracy of the images is typically 1 to 2 mm. Recently, it has become possible to use MRI as the primary data set for RTP by using advantageously open MR systems. Open MR scanners are preferred for their patient friendliness, patient positioning flexibility, ease of patient accessibility for interventional procedures and cost effectiveness. Patient anxiety is reduced by the open design, especially

20   for the claustrophobic patient. Technologists also benefit from the open design through ease of patient positioning and more friendly, direct patient communications. With open systems, image quality has also benefited from the patient positioning flexibility because images can always be collected at or near the magnetic center (isocenter). Since especially gradient non-linearity leads to distorted images, a special gradient distortion correction (gdc) software

25   correction is applied to improve the accuracy. However, for larger patients the accuracy at greater distance from the isocenter is not sufficient. The resulting errors in the measured position of external markers can become unacceptable. With the proposed inventive method, this error can be reduced allowing improved accuracy and wider use of MRI for RTP.

To reduce the errors due to image distortion, the patient is imaged in two or

30   more positions. First, the patient is imaged with the lesion approximately in the isocenter of the MR system. In these images, some or all markers may be so far from the isocenter, that even with gradient distortion correction, the geometrical position of the markers is measured not accurate enough, i.e. the markers depicted on the original image with the large FOV do not correspond exactly with the real positions of the markers. Thus, the positions of markers

5

(4,5,6,7,8,9,10,11) of the patient 1 are detected incorrectly. In order to correct this mistake, the patient is imaged in at least one additional position, with the patient off-center in such a way that the markers on one side will be closer to the isocenter and therefore can be measured more accurately. If needed, this can be repeated moving the patient the other way

5 for markers on the other side of the patient. So, the patient is shifted to successive positions relative to the isocenter and, thereby shifting the regions of interest relative to the imaging FOV. The shift of the patient table relative to the isocenter determines the accurate geometrical position of the external or fiducial markers (4,5,6,7,8,9,10,11), which positions are merged into the image with the large FOV. This is accomplished e.g. by shifting the

10 fiducial markers (4,5,6,7,8,9,10,11) to the correct positions. On the other hand a composite image data set can be created from the acquired data taken from the various regions of interest across the patient by merging the images by overlapping corresponding parts with accurate geometrical positions of the images.

Fig. 1 depicts the above described situation. Three imaging positions of a large

15 patient 1 having a lesion 2, are schematically shown. The ellipse represents an MR image of a large person 1. On the left side and on the right side of the patient external or fiducial markers 4,5, drawn as small squares, are fixed on the patient 1. These external or fiducial markers can also be fixed on a fixation device. The circle represents the optimal field of view FOV^{opt} 3 wherein the geometrical accuracy of the imaging system is acceptable, i.e. has a

20 prescribed tolerance. For example, the requirement of a prescribed tolerance could mean only using those parts of the image where the distortion produces an inaccuracy in the identification of the position of structures of less than 1mm or even of, say, less than 0.5mm or of less than 0.25mm. Using the image portions within an identified FOV^{opt} with such a prescribed tolerance allows the parts of the image which contain minimal distortion of the

25 relative positions of anatomical structures to be used to provide information for the radiotherapy, or RT, planning process. The radius of the circle represents the distance from the isocenter at which the linearity starts to break down. The whole imaging field of view FOV of the MR image is larger than the FOV^{opt} 3 and usually comprises the total image of the lesion 2 and the fiducial markers 4,5. Fig. 1a shows the patient 1 positioned with its lesion

30 2 near to the isocenter of the MR apparatus. Both fiducial markers 4,5 are out of the boundary of FOV^{opt} 3. That means that the geometrical position of the lesion 2 is very accurate, but the markers 4,5 are in the FOV where image distortion is inevitable, even by applying of gradient distortion correction software, and their geometrical position is inaccurate. In such a manner the fiducial markers are not usable for RTP. Fig. 1b shows the

6

patient 1 positioned with its right fiducial marker 4 within the FOV^{opt} 3 and the lesion 2 near to the margin of the FOV^{opt} 3. This position gives an accurate geometrical position in the MR image for the right marker 4 and Fig. 1c shows the patient 1 positioned with its left fiducial marker 5 and lesion 2 within the FOV^{opt}. The shifts of the patient can be measured to

5   determine the correct geometric position of the markers. These imaging positions with its accurate geometric positions of lesion 2 and fiducial markers 4,5 are merged in the image acquired with the lesion 2 positioned close to the isocenter (Fig. 1a). Thus, the images with the optimal FOV in Figs. 1a to 1c are merged to a single image. On the other hand the images with the accurate geometrical positions of the fiducial markers 4, 5 can also be merged in the

10   image with large FOV, wherein the lesion 2 is imaged in close vicinity of the isocenter.

          Fig. 2 shows three imaging positions of a large person 1, using four fiducial markers, namely on both sides anterior and posterior. Fig. 2a depicts the patient 1 positioned with its lesion 2 near to isocenter and all fiducial markers 6,7,8,9 are out of the boundary of FOV^{opt} 3. The geometrical position of the lesion 2 is very accurate, but the geometrical

15   positions of the markers 6,7,8,9 are inaccurate. Fig. 2b shows the patient 1 shifted left and positioned with its right posterior and anterior fiducial markers 6,7 within the FOV^{opt} 3 and the lesion 2 near to the margin of the FOV^{opt} 3 and Fig. 2c shows the patient 1 shifted right and positioned with its left posterior and anterior fiducial markers 8,9 and lesion 2 within the FOV^{opt}. These imaging positions permit, as previously described, the merging of accurate

20   representations of the geometric positions of the fiducial markers 6,7,8,9 in Fig. 2a.

          Fig. 3 shows three imaging positions of a large person 1, using two fiducial markers, namely anterior and posterior. Fig. 3a depicts the patient 1 positioned with its lesion 2 near to isocenter and all fiducial markers 10,11 are out of the boundary of FOV^{opt} 3. The geometrical position of the lesion 2 is very accurate, but the geometrical positions of the

25   markers 10,11 are inaccurate. Fig. 3b shows the patient 1 shifted down and positioned with its anterior fiducial marker 10 within the FOV^{opt} 3 and the lesion 2 near to the margin of the FOV^{opt} 3 and Fig. 3c shows the patient 1 shifted up and positioned with its posterior fiducial marker 11 and lesion 2 within the FOV^{opt}. These imaging positions permit, as described above, the merging of accurate representations of the geometric positions of the fiducial

30   markers 10,11 in Fig. 3a.

          The drawings show fiducial markers 4,5,6,7,8,9,10,11 placed laterally (left and right), anterior or posterior on the patient. These markers may also be placed on the patient or be fixed on a fixation device at other positions, e.g. on the midline of the patient, which runs from head to feet. The point is to have fiducial markers at positions which can be positioned

7

within the area close to the isocenter of the magnet where the position measured in the MR images is still accurate. For not too large patients, midline markers as mentioned above, will be possible - either because this position will be within the FOV^{opt} or because the patient is moved higher or lower so that it is. However for very large patients, midline markers will be

5   relatively far from the isocenter and cannot in such a situation be measured accurately, because the magnet bore or magnet gap limits the possible offset in the anterior direction.

It is now clear how the creation of a composite image can be achieved by overlapping the corresponding parts of the acquired images. The merging of the images can be achieved by registering the portions of the images which correspond to each other. For

10   example, a composite image can be formed from the merging, or registration, of the three FOV^{opt} 3 sections shown in Figs. 1a, 1b and 1c. The FOV^{opt} from Fig. 1a will have an overlapping area with the FOV^{opt} from Fig. 1b, the overlapping areas in common being respectively on the right hand side of FOV^{opt} in Fig. 1a and on the left hand side of FOV^{opt} in Fig. 1b. These two sections represent the same anatomical parts. Registration techniques can

15   be used to register these two overlapping areas with each other and thus bring the two FOV^{opt} sections from image 1a and 1b into line with each other. Similarly, the FOV^{opt} from Fig. 1a will have an overlapping area with the FOV^{opt} from Fig. 1c, the overlapping areas in common being respectively on the left hand side of FOV^{opt} in Fig. 1a and on the right hand side of FOV^{opt} in Fig. 1c. Again, registration techniques can be used to register these two

20   overlapping areas with each other, thus bringing the two FOV^{opt} sections from image 1a and 1c into line with each other. If all such corresponding overlapping areas in all FOV^{opt} sections are registered, or merged, in this way then a composite image will result.

With an open MRI system, images of lesion 2 can always be collected at or near the isocenter. This system permits to enter the patient into the MR device sideways. For

25   this purpose the system comprises a patient table which permits to reposition the patient 1 in the left-right direction within the open MRI. With this patient table it is possible to bring the fiducial markers 4;5;6;7;8;9, which are fixed to the patient or on a fixation device, successively within the FOV^{opt} 3 as near as possible to the isocenter of the MR system. When the patient is moved up or down, also markers 10,11 can be moved and positioned within the

30   FOV^{opt} 3. Further a software may be applied which is called Gradient Distortion Correction (GDC) to correct images for gradient-induced distortion. This leads to accurate images of the open MR system within the mentioned FOV^{opt} 3.

The fiducial marker position, which is, thanks to the displacement, moved within the FOV^{opt} 3 therefore can be accurately determined by measuring the shift of the

8

patient with reference to the position with lesion 2 in the isocenter position. The images of
these positions should be merged with the image acquired with the lesion 2 positioned close
to the isocenter to create images with accurate positions of fiducial markers. This can be
achieved simply by correcting the positions of the markers in the image obtained in the

5   position depicted in Fig. 1a, 2a, or 3a, respectively. For example, this can be done by using
the measured shift, or displacement, of the position of the patient when translating the patient
from the patient position at which the image of the lesion was acquired to the patient position
at which the image of the fiducial marker was acquired. For example, the patient is first
positioned and an image of the lesion is acquired showing a central reference point, as is

10 known. The patient is then shifted a number of centimeters to the right before the acquisition
of an image of a fiducial marker. The image containing the fiducial marked in an undistorted
portion of the image also contains a central reference point. The numerical value of the
physical shift undergone by the patient is the distance in reality between the two central
reference points in the two images. If the accurate position of the fiducial marker can know

15 by deduced from the second image, it's actual position in the first image, that of the lesion,
can be calculated. The first image can then be corrected. Alternatively, the process can be
performed the other way around, with the position of the lesion, or region of interest, being
corrected in the image which carries accurate positional information about the fiducial
markers. Alternatively, the images can be merged where a composed image is created

20 primarily from the parts of the images covered by the FOV^{opt} 3 as measured in positions 1a,
1b,1c, or 2a,2b,2c, or 3a,3b,3c, respectively. This merging of images can be performed using
image registration techniques.

With the proposed method and system, geometrical positions of a lesion 2 and
fiducial markers can be determined accurately which is also allowing improved accuracy and

25 wider use of magnetic resonance imaging (MRI), especially for open MRI in radiotherapy
treatment planning and simulation, where the exact location and extent of the tumor needs to
be known as good as possible. However, also a closed MR system with a main magnet with a
large bore can be used, provided that the patient support can be moved sideways and/or up
and down.

30 The invention can be advantageously utilized in practice by first performing
the acquisition of the magnetic resonance images using a magnetic resonance imager with a
patient table, patient bed or other patient support means which can be translated or shifted
relative to the isocenter of the magnetic field. Fiducial markers, otherwise known as external
markers or surface markers, are placed on the surface of the patient. The patient is positioned

9

on the patient table or other support means and positioned for the initial image. This may be the image acquired with the lesion, or region of interest, positioned close to the isocenter of the magnetic field, or at least positioned in the FOV^{opt}, or optimal field of view, of the magnetic field. This initial image is acquired. The position of the patient is then shifted, or

5   displaced, to another position in which one of the fiducial markers is positioned close to the isocenter of the magnetic field, or at least positioned in the FOV^{opt}. The second image is then acquired. Further shifts are performed and further images are acquired until all fiducial markers and the region of interest, or lesion, are represented in a FOV^{opt} of an image. It will be obvious to those skilled in the art that the order in which the images are taken is

10   immaterial.

Following imaging the acquired images are used to form an image suitable for radiotherapy planning using the other steps of the method of the invention. The formation of such an image may take place at the controls of the magnetic resonance imager, or make take place on a separate work station or may also take place in a radiotherapy treatment planning

15   system or workstation. Once a suitable image is formed it is used for radiotherapy treatment planning using known treatment planning techniques.

The production of the image suitable for radiotherapy treatment planning may involve using the known shifts of the patient between images, as has been described. Image production may also involve simply merging, or registering the images as has been described.

20   Image production may also however involve a combination of the two, for example in which the accurate positions of the fiducial markers are calculated and then used in the image containing the accurate image of the lesion to register in the accurate portions of the images containing the fiducial markers in the optimal field of view, or FOV^{opt}. In this case a composite view would be formed utilizing the best portions of each overall image. In fact, the

25   single image which results, and which may then be used for radiotherapy treatment planning, may be one of the originally acquired images which has been corrected according to one of the methods described above, or, could be a new image which is a composite of portions of the original images.

The present invention is therefore not only directed to the method for using the

30   images but also to a specific designed magnetic resonance imaging system, as defined in independent claim 10, and a computer programme as defined, as in independent claims 15 and 18, for the execution of the above described method.

The computer programme is stored on a computer usable medium and is designed to use magnetic resonance images and to cause the execution of the different steps

of the above mentioned method. The computer programme as defined in claim 15 is particularly advantageously employed in a magnetic resonance imaging system which generates a magnetic field with a magnetic center (isocenter), as origin for locating anatomical targets in a patient, e.g. for radiotherapy. At least one fiducial marker is applied to

5   the body of the patient at a distance from the isocenter.

It is further noted that the method according to the present invention can also be used on a workstation or a radiotherapy planning system remote from the magnetic resonance imaging system, so that the radiotherapy treatment planning can be executed, for example, in a different room, or a different hospital department, or even a different hospital.

10   A workstation or a radiotherapy planning system according to the invention is defined in independent claim 12.